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ACCOUNTING FOR THE TIME OF ULTRASONIC FUEL PROCESSING IN THE SURFACE TENSION COEFFICIENT

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ABSTRACT

The issues of fuel cooling during cavitation processes are considered, which allow increasing the efficiency of the engine. In the critical energy expended on the formation of the cavitation bubble, a correction factor is introduced, depending on the time of processing the fuel by ultrasound. Clarification of the dependence - for the case of acoustic or vibration cavitation - allows to illustrate the increase in energy taken from the fuel by 5...10%.

Keywords: cavitation, surface tension, cooling, fuel, ultrasound.

INTRODUCTION

It is known that fuel circulates from the tank through several fuel pumps to the engine, with a certain part of it returning to the tank. Such a path through the heated elements of the fuel system can contribute to a significant fuel heating, especially if a small volume is used (the vehicle's tank is rarely complete). When the fuel is heated, the cooling effect on the incoming charge decreases and a power loss in the range of 0.5...1% is observed. This particularly applies to the Common Rail system - the temperature of the fuel circulating in it can reach 140°C. The increased temperature of the fuel can lead to a decrease in the efficiency and durability of fuel equipment, the accelerated aging of plastics and elastomers, and also to require the installation of "traps" for hydrocarbons in the fuel system.

According to the manufacturers of diesel generators, the following effects can result from the increase in the fuel temperature above 55°C [1]:

- the engine cannot develop full power, since with increasing fuel temperature, the amount of incoming air to the cylinders is reduced and the fuel does not completely burn;
- scuffing may appear on the working surfaces of the fuel equipment due to the loss of viscosity of the fuel, and, consequently, it's lubricating properties with increasing its temperature;
- stiffer operation of the engine due to earlier ignition of preheated fuel;
- self-stopping of the engine due to the fuel system airing with vapors of light fractions emitted from the fuel at high temperature, etc.

According to Nissan, fuel support in the cold state is extremely important for high-performance engines and cars with high performance, especially if they are used in hot climates [2].

Since one of the problems associated with the fuel injection system is the amount of heat added to the fuel that is not used for combustion, various cooling systems for "returning" fuel are often used [3]. As a practical implementation of such a system, the $CryO^2$ Fuel Chiller System from DEI Engineering, whose fuel cooling process is based on the cryogenic properties of CO_2 liquid carbon dioxide: the fuel passes through the central chamber of the device and enters the cryogenic chambers, where it is substantially cooled.

MATERIALS AND METODS

The review [4] summarizes information on the effect of wave effects on various processes in chemistry and petrochemistry. Their classification by nature and by the physical bases of the processes taking place in this process is given. The main stages in the technology of oil refining (production, primary and deep oil refining, the use of fuels, environmental problems), in which wave processing plays a significant role, are considered. The questions of the mechanism of the effect of wave processes on oil systems are discussed.

We have substantiated and developed a method of accounting for changes in the surface tension coefficient of a liquid in the case of vibration or acoustic cavitation in it. Diesel fuel of the state sample 305-2013 was selected as an experimental liquid, which was processed for 0 to 600 seconds in the ultrasonic fuel treatment apparatus [9] at a frequency of 43 kHz and a power source of 60 watts. The surface tension coefficient was measured by the droplet separation method.

RESULTS AND DISCUSSIONS

The essence of cooling the fuel is that the colder one takes up a smaller volume, so it has a greater ability to absorb heat from the input charge, thereby increasing the amount of air directed into the cylinder. The cooling effect allows you to pack more oxygen molecules in each charge entering the cylinder. According to the specialists of the Ferrari team, who used the device for cooling the fuel on racing cars, cooling the fuel before injection gives an increase of 0.5% of the power for every 10°C.

On the other hand, if the fuel is too cold, it will not be able to heat up quickly enough when passing through the fuel supply system of the car and, further, when injected. As a result, a certain amount of fuel will not burn completely and, therefore, will not participate in useful work, thereby reducing the efficiency of the engine. Therefore, there must be some compromise in choosing

the temperature of the fuel and, therefore, the system of its cooling.

The effects of cooling the fuel can also be present at the micro level, for example, in cavitation processes in liquids. According to [5], the critical energy expended on the formation of a cavitation bubble can be found from the formula:

$$W_k = \frac{4}{3}\pi\sigma R_k^2, \quad (1)$$

Where
σ is the coefficient of the surface tension of the liquid, N/m; R_k is the radius of the cavitation bubble, m.

The mechanism of growth of a vapor bubble when boiling in a free volume is similar to the growth of a vapor bubble during cavitation - both are realized due to the heat input of the liquid overheating from the thermal boundary layer that adjoins the bubble surface. This similarity makes it possible to use the solution proposed by M. Plesset and S. Zwick [6] to estimate the growth of the bubble vapor phase during cavitation:

$$\left(\frac{\partial R}{\partial \tau}\right)_{n=0} = \sqrt{\frac{3}{\pi}} \cdot \frac{\lambda \Delta T_h}{r\rho'' a^{0.5}} \tau^{-0.5}, \quad (2)$$

Where
λ is the thermal conductivity of the fluid, W/(m·K); ΔT_h - degree of liquid overheating, K; r is the specific heat of vaporization, J/kg; ρ'' is the vapor density at the saturation line; a is the thermal diffusivity of the liquid, m^2/s; τ is the time, s; $n = 0$ refers to the bubble surface.

From equation (2), we can obtain an expression for the radius $R_{(n=0)}$:

$$R_{n=0} = R_k + 2\sqrt{\frac{3}{\pi}} \cdot \frac{\lambda \Delta T_h}{r\rho'' a^{0.5}} \tau^{0.5}. \quad (3)$$

In [7] the authors, using expressions (1) and (3), obtained a formula describing the total amount of heat spent on the formation of vacuum bubbles that do not interact with one another under steady-state vapor cavitation in a liquid:

$$Q_\Sigma = N_b \cdot \left[(i+1) W_k + \sum_{i=0}^{k} Q_n (i\Delta\tau) \right], \quad (4)$$

Where Q_n is the amount of heat expended on bubble growth, J; i is the step number by time.

It was assumed in [7] that simultaneously at the initial instant of time, N_b-bubbles with the same critical size R_k were born, and their formation from the liquid was taken to be the energy equal to the product of the number of nucleated bubbles per critical energy expended on the formation of one cavitation bubble:

$$\varepsilon = N_b W_k. \quad (5)$$

In addition, the amount of heat taken away from the liquid is composed of the heat expended in the nucleation of bubbles, plus the heat expended on the growth of bubbles, and during the growth of the conventionally "first" batch of bubbles, the "second", "third", and so on, etc.

However, it is known that the coefficient of surface tension of a fluid in vibrating cavitation depends on the frequency of oscillations [8], and when estimating the total amount of heat by formula (4) it was not taken into account.

A method is proposed for taking into account changes in the coefficient of surface tension of a liquid in the case of the presence of vibrational or acoustic cavitation in it. As an experimental fluid, diesel fuel DT GOST 305-2013 was chosen, which was processed for 0 to 600 seconds in a device for ultrasonic processing of fuel [9] at an oscillation frequency of 43 kHz and an oscillation source power of 60 W. The surface tension coefficient was measured by the drop separation method (Table-1).

Table-1. Dependence of surface tension coefficient of fuelfrom the time of its sonication.

***t*, s**	**0**	**10**	**20**	**30**	**40**	**50**	**60**	**90**	**120**	**600**
$\sigma_{exp}\cdot 10^{-3}$, N/m	26.49	27.73	28.06	28.39	28.61	28.73	28.73	29.06	29.06	29.28
$\Delta\sigma$, %	-	4.72	5.96	7.17	8.00	8.46	8.46	9.70	9.70	10.53

Analysis of the data in the table shows that the increase in the surface tension coefficient mainly occurs up to 50 seconds (by 8.46%), and further - from 60 to 600 seconds - an increase of only 2.07%. Probably, a small increase in the surface tension coefficient in the processing range of 60...600 seconds is associated with the process of heating the fuel by supplying energy from the radiator, when the reverse process begins - a decrease in the coefficient of surface tension due to temperature growth [10]. As a result, the growth rate of the surface tension coefficient decreases from almost 8.5% to 2%.

On the basis of the above, to approximate the formula by changing the surface tension coefficient, it is sufficient to use the range 0...50 seconds (Figure-1).

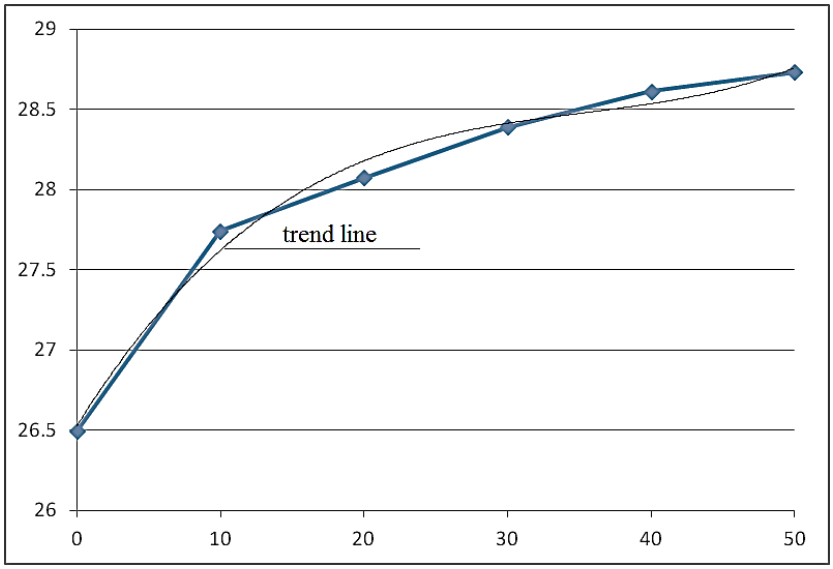

Figure-1. Approximation of the change in the coefficient of surface tension in the range 0...50 seconds.

The approximating dependence for the coefficient of surface tension relative to the initial value obtained experimentally can be represented by the following equation:

$$\sigma_{appr} = \sigma_{\exp} + 0.00004t^3 - 0.0037t^2 + 0.13t, \quad (6)$$

Where
t is processing/existence time, sec. The dimension of the coefficient for t^3 is [N/(m·s^3)], t^2 - [N/(m·s^2)], t - [N/(m·s)]. To assess the feasibility of the practical use of equation (6), it is necessary to verify it for adequacy, for example, using the Fisher criterion. We represent the calculations in the form of Table-2, while the corresponding dependencies for nonlinear models were used to calculate the correlation coefficient and the calculated Fisher criterion ($F_{calcul.}$).

Since $F_{calcul.} > F_{table}$, the equation is adequate and it can be used to approximate the values of the surface tension coefficient with an average error of approximation of 0.71%.

As a result, equation (1) can be modernized by introducing the correction established by equation (6):

$$W_k = \frac{4}{3}\pi\left(\sigma + 0.00004t^3 - 0.0037t^2 + 0.13t\right)R_k^2. \quad (7)$$

Then equation (5) is also modernized as follows:

$$\varepsilon = N_b\left[\frac{4}{3}\pi\left(\sigma + 0.00004t^3 - 0.0037t^2 + 0.13t\right)R_k^2\right]. \quad (8)$$

Table-2. Estimation of the adequacy of equation (6).

t, s	σ_{exp}, N/m (according to Table 1)	$\sigma_{calcul.}$,N/m (according to equation(6))	Standarddeviation nt	Standard deviation σ	Coefficient of variation t	Coefficient of variation σ	Coefficient of correlation	Coefficient of determination	$F_{calcul.}$	F_{table}at [11]	Average approximation error,%
0	26.49	26.49	17.08	0.75	0.68	0.03	0.964	0.93	53.06	6.61	0.71
10	27.74	27.46									
20	28.07	27.93									
30	28.39	28.14									
40	28.61	28.33									
50	28.73	28.74									

Similarly, the total amount of heat spent on the formation of non-interacting vacuum bubbles with stationary cavitation in diesel fuel will change if acoustic or vibration cavitation is present:

$$Q_{\Sigma} = N_b \left[(i+1) \left[\frac{4}{3} \pi \left(\sigma + 0.00004t^3 - 0.0037t^2 + 0.13t \right) R_k^2 \right] + \sum_{i=0}^{k} Q_n (i\Delta\tau) \right]. \quad (9)$$

As a result, it can be concluded that energy will be selected from the fuel, depending on the time of existence in it of acoustic or vibration cavitation, and it will be more by 5...10% than in equation (1).

CONCLUSIONS

The appearance of volumetric vapor cavitation in a metastable liquid, accompanied by its sonication, allows to increase by 5...10% the selected critical energy, and it becomes possible to control the process of energy extraction due to a change in the processing time.

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CONFLICT OF INTEREST

The authors have no conflict of interest to declare.

REFERENCES

[1] Electronic resource. URL: http://cons-systems.ru/rekomendatcii-po-kspluatatcii-dizelnykh-lektrostantciy(Access mode 04/13/2018).

[2] Electronic resource. URL: https://www.atomic-shop.ru/part/87091-ALP.07.07.0102-2/(Access mode 04/13/2018).

[3] Chyo T., Kanefsky P., Armesto C., Shah A., Schoen D. 2011. Diesel fuel cooling system and control strategy. Patent No. US 8, 006, 675 B2; published: 30.08.2011.

[4] Pivovarova N. A. 2019. Use of wave effect in processing of the hydrocarbonic raw material (review). Petroleum Chemistry. 59(6): 559-569. doi:10.1134/S0965544119060148

[5] Skripov V. P. 1972. Metastable liquid. Moscow, Nauka. p. 307.

[6] Plesset M. S., Zwick S.A. 1954. The Growth of Vapor Bubbles in Superheated Liquids. Journal of Applied Physics. 25(4): 38-43.

[7] Urbanovich L. I., Kramchenkov E. M., Gubarev V. Ya. 2006. Growth of the system of vapor bubbles with volumetric cavitation. Proceedings of the 4th Russian National Conference on Heat Exchange. 4: 224-227.

[8] Khmelev V. N., Shalunov A. V., Golikh R. N., Shalunova A. V. 2011. Identification of optimal modes and conditions of ultrasonic action for spraying viscous liquids. Electronic Journal Technical Acoustics. 10: 1-15.

[9] Simdyankin A. A., Pukov R. V. 2017. Estimation of fuel consumption of engines with ultrasonic fuel treatment. Engineering and equipment for the village. 11(245): 12-17.

[10] Sivukhin D. V. 2005. General Course of Physics. Thermodynamics and molecular physics. Moscow, Fizmatlit.

[11] Electronic resource. URL: http://chemstat.com.ru/node/19(Access mode 04/13/2018).